A Fuel Cell Application and Beijing Air Pollution Control

Jingyao Xu
Te Xiao

Bachelor's Thesis

___.___.______ ________________________________

Bachelor's degree (UAS)

SAVONIA UNIVERSITY OF APPLIED SCIENCES **THESIS**
Abstract

Field of Study Technology, Communication and Transport			
Degree Programme Degree Programme in Industrial Management			
Author(s) Jingyao Xu, Te Xiao			
Title of Thesis A Fuel Cell Application and Beijing Air Pollution Control			
Date	17.3.2015	Pages/Appendices	51/4
Supervisor(s) Harri Heikura			
Client Organisation/Partners			

Abstract

This paper mainly deals with the promotion of fuel cell vehicles in Chinese typically polluted city—Beijing. In order to implement the project successfully, two major motivators, from the respective aspect of the fuel cell technical characteristics as well as the Beijing current pollution, were accordingly studied and analyzed in the first four chapters. Subsequently, the authors deepened the understanding of the Chinese development environment towards fuel cell vehicles in the fifth chapter. This can be seen as the third motivator for the fuel cell vehicle project. All the above researches and analyses were the supportive background for the project deployment.

The study results in the decision of joint venture form and its corresponding development strategies. Finally, in the conclusion chapter, the main findings are summarized and the author's conclusions are presented, not only regarding the Beijing pollution studies, but also about strategies in the joint venture development as well as further steps recommendations.

Keywords
FCV(Fuel Cell Vehicles), PEM(Poly Electrolyte Membrane), Beijing air pollution, PM2.5

CONTENTS

ABBREVIATIONS AND DEFINITIONS

AFC	Alkaline Fuel Cell
CHPP	Coal Handling and Preparation Plant
CPP	Coal Preparation Plant
DMFC	Direct Methanol Fuel Cell
FCV	Fuel Cell Vehicles
MCFC	Molten Carbonate Fuel Cell
MNC	Multinational Corporation
PAFC	Phosphoric Acid Fuel Cell
PEM	Proton Exchange Membrane
PEMFC	Proton Exchange Membrane Fuel Cell
SME	Small and Medium-sized Enterprises
SOFC	Solid Oxide Fuel Cells

1 Introduction

Covering 9.6 million square kilometres, and raising more than 1.3 billion citizens, China is worldwide acknowledged as the second largest country in the world. Both the enormous population and sheer scale of the country lead to an avalanche of challenges in respect of energy supply. Viewing the structure of Chinese energy consumption, the coal, from which more than 80% of the electricity is generated, still predominates over other sources. These emissions contributed to China's elevation to the top of the world's CO_2 emitters (in absolute terms) in 2007, overtaking the USA by a vast gap (Fuel Cell Today 2012). Therefore this thesis is designed to reflect and control the problematic situation with respect to energy in China. The solution considered is the promotion of FCV project.

Fuel cells are not a new technology to China, but in fact have been researched and developed since the 1970s, when a prototype alkaline fuel cell was developed for use in its domestic space programme. This unit never left the confines of the laboratory, but the interest in fuel cells remained with PEMFC technology emerging as the dominant technology. Through the 1990s research focused on automotive applications, but attempts to gain interest from commercial partners proved fruitless. Around 1999, the government extended the electric vehicle R&D investment to include fuel cell technology, and since 2000, a number of demonstration programmes have taken place raising the profile of fuel cells in the eyes of both the government and the public. Current academic and commercial interest in fuel cells ranges from very small portable units for powering torches and consumer electronics, through larger stationary systems for backup power and all the way up to fuel cell electric vehicles and fuel cell buses. (FuelCellToday 2012.)

2 Fuel Cell Technology

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent (Khurmi & Sedha 2013). All of the different types of fuel cell have one thing in common: they generate electricity from hydrogen and oxygen (Seifried & Witzel 2010).

2.1 Theory Background

Hydrogen (or a gas such as natural gas and methanol that contains hydrogen) inputs from one side; oxygen (or ambient air), from the other (Seifried & Witzel 2010). At the anode, hydrogen is split into protons contributed by the catalyst. Then these protons pass through the electrolyte which is a special membrane that only the protons can penetrate. From the anode the electrons flow out of the fuel cell to the electric appliance. After this process they go to cathode and recombine with the protons and oxygen to form water. The typical fuel cells operate as the picture illustrates below.

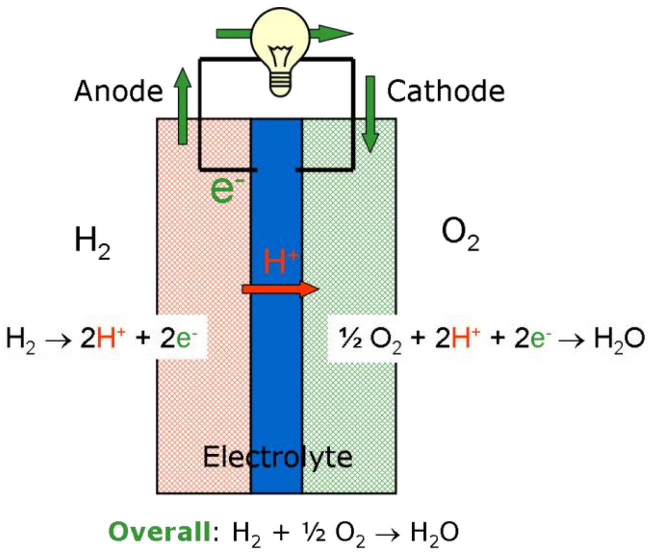

Figure 1. How fuel cells work. (Solid state Ionics and electroceramics research group 2013.)

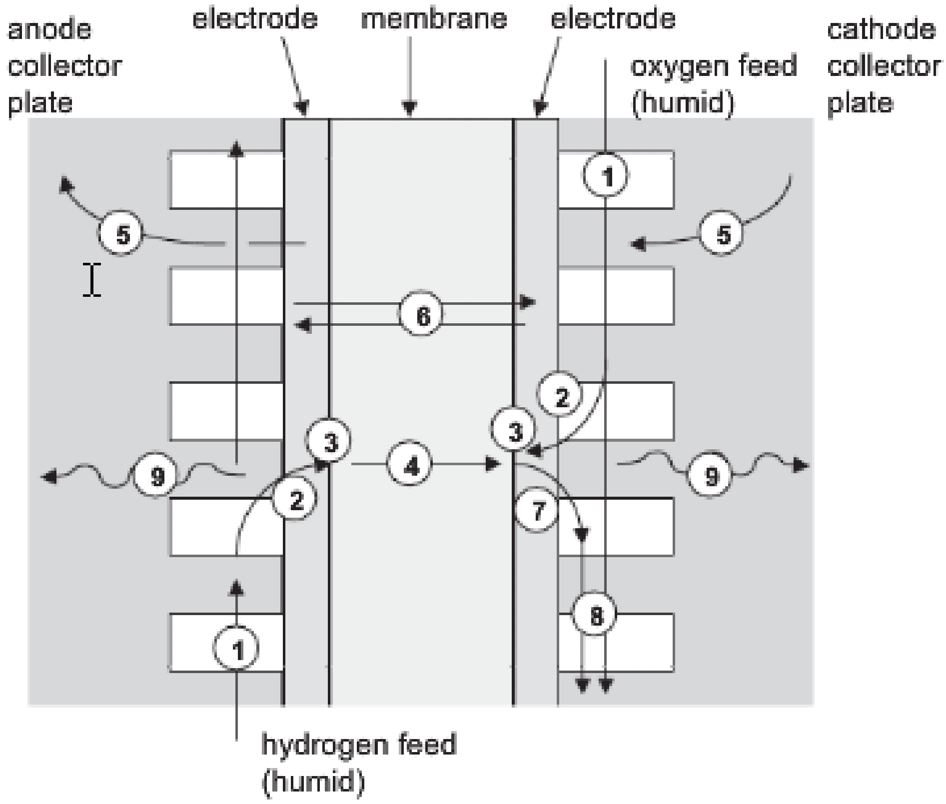

Figure 2. Main cell components (not in scale) and processes. (Barbir 2013.)

The picture above explains in detail the processes taking place inside the fuel cell (the numbers correspond to Figure 2):

1. Gas flow through the channels; porous layers make convective flows possible
2. Gas diffusion through porous media
3. Electrochemical reactions (all the intermediate steps are included)
4. Proton transport through proton conductive polymer membrane
5. Electron conduction through electrically conductive cell components
6. Water transport through polymer membrane including both electrochemical drag and back diffusion
7. Water transport (both vapor and liquid) through porous catalyst layer and gas diffusion layers
8. Two phase flow of unused gas carrying water droplets
9. Heat transfer

2.2 Technology Types of Fuel Cell

All fuel cells are based around a central design using two electrodes separated by a solid or liquid electrolyte that carries electrically charged particles between them (Fuel cell today). At the electrodes fuel cells use catalyst to speed up the reaction. Fuel cell types are generally classified by the kind of electrolyte they use. This classification determines particular materials and fuels and is suitable for different applications.

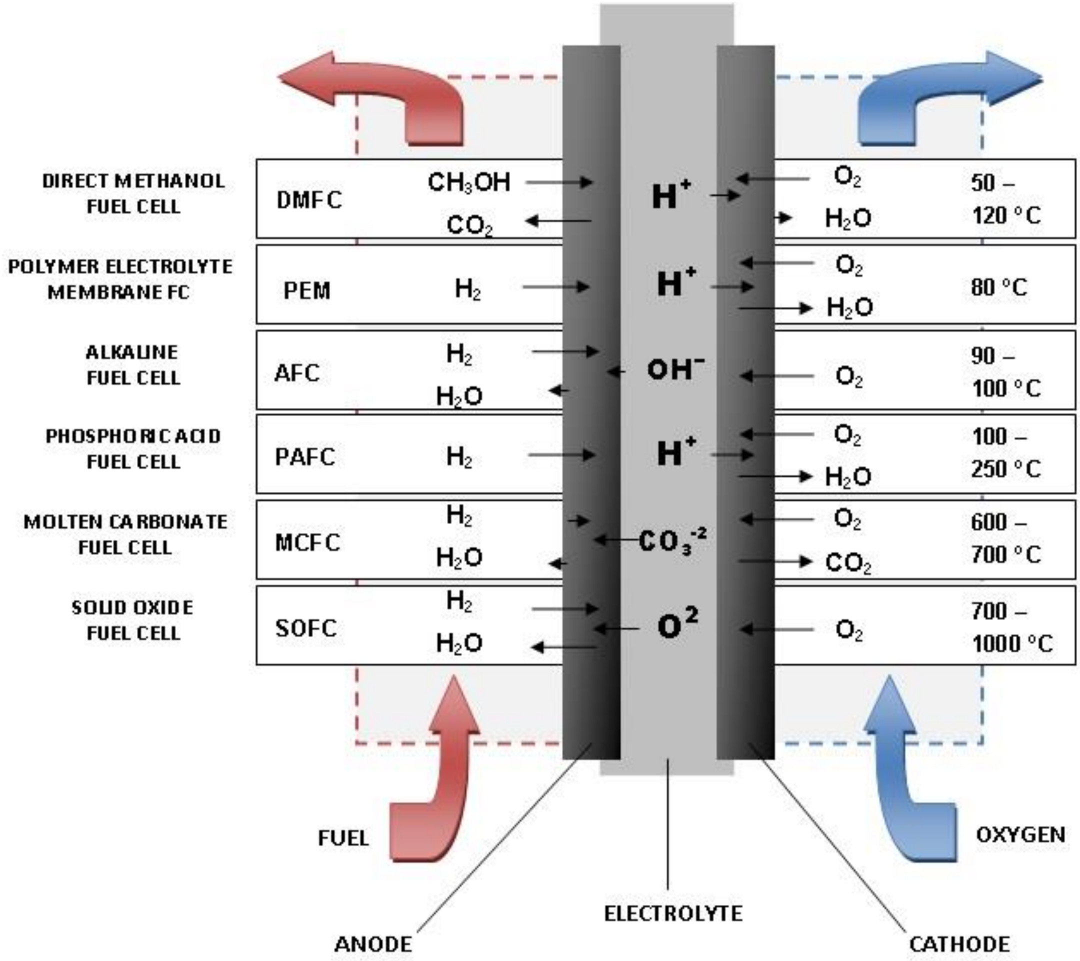

Figure 3. Types of Fuel Cells. (Fuel Cells 2000 2015.)

As Fuel Cells 2000 (2015) summarizes, the categories of fuel cell are:

- DMFC (Direct Methanol Fuel Cell)
- PEMFC (Proton Exchange Membrane Fuel Cell)
- AFC (Alkaline Fuel Cell)
- PAFC (Phosphoric Acid Fuel Cell)
- MCFC (Molten Carbonate Fuel Cell)
- SOFC (Solid Oxide Fuel Cells)

In Figure 3, we can see each fuel cell type has its own unique chemistry, such as different operating temperatures, catalysts, and electrolytes. A fuel operating characteristics help define its application.

There are four major fuel cell technologies – carbonate, solid oxide, phosphoric and polymer membrane. Each type is suited for specific applications such as large or small scale applications and stationary or mobile applications. However, there is not a fuel cell that is well suited for all applications. The table below shows the property of different fuel cell technologies.

Table 1. Types of fuel cells. (Fuel cell energy, 2013.)

	MW Class	**Sub-MW Class**		**Micro CHP**	**Mobile**
Technology	Carbonate (MCFC)	Phosphoric Acid (PAFC)	Solid Oxide (SOFC)	PEM / SOFC	Polymer Electrolyte Membrane (PEM)
System size range	300kW – 2.8MW	400kW	up to 200kW	< 10 kW	up to 100 kW
Typical Application	Utilities, large universities, industrial – baseload	Commercial buildings – baseload	Commercial buildings – baseload	Residential and small commercial	Transportation
Fuel	Natural gas, Biogas, others	Natural gas	Natural gas	Natural gas	Hydrogen
Advantages	High efficiency, scalable, fuel flexible & CHP	CHP	High efficiency	Load following & CHP	Load following & low temperature
Electrical efficiency	43%-47% (higher w/ turbine or organic rankine cycle)	40% – 42%	50% – 60%	25% – 35%	25% – 35%
Combined Heat & Power (CHP)	Steam, hot water, chilling & bottoming cycles	Hot water, chilling	Depends on technology used	Suitable for facility heating	No, which is an advantage for transportation

The main topic in this thesis is fuel cell vehicles. So from Table 1, the technology of polyelectrolyte membrane (PEM) is suited for mobile and small scale application like transportation. In the next chapter the authors are going to discuss the PEMFC – polyelectrolyte membrane fuel cell, which is one of the fuel cell types based on PEM technology.

2.3 PEMFC Technology

PEMFC cells operate at relatively low temperatures (below 100 °C, see Table 2) and can tailor electrical output to meet dynamic power requirements. Due to the relatively low temperatures and the use of precious metal-based electrodes, these cells must operate on pure hydrogen. PEMFC cells are currently the leading technology for light duty vehicles and materials handling vehicles, and to a lesser extent for stationary and other applications. (Fuel cell today.)

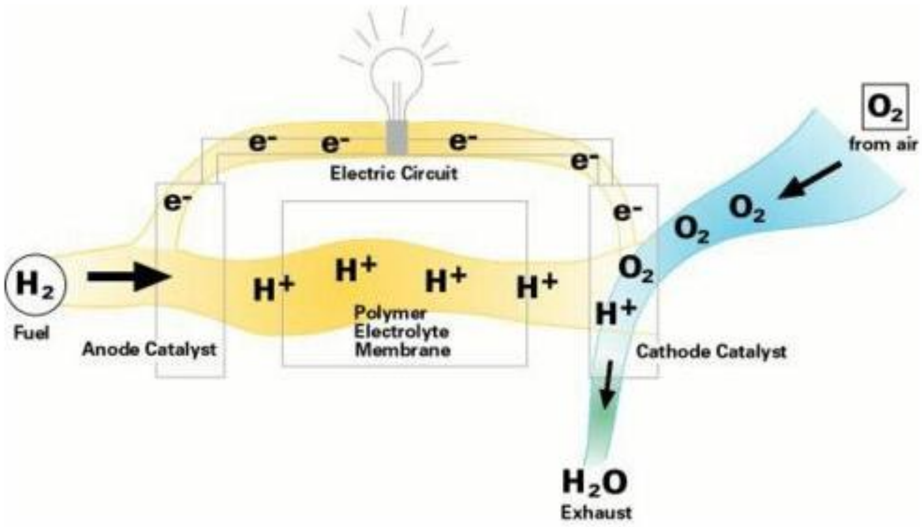

Figure 4. PEMFC fuel cell. (altenergymag.)

The proton exchange membrane fuel cell (PEMFC) components and their characteristics are:

- Electrolyte: Solid polymer membrane
- Catalyst: Platinum is the most active catalyst for low-temperature fuel cells
- Electrical Efficiency: 40-60 percent

Table 2. Low temperature PEMFC & high temperature PEMFC.

	Low temperature PEMFC	**High temperature PEMFC**
Operating temperature	80-100 °C	Up to 200 °C
electrolyte	Water - based	Mineral acid - based
Pt loading	0,2-0,8 mg/cm²	1,0-2,0 mg/cm²
CO tolerance	<50 parts per million	1-5% by volume
Other impurity tolerance	Low	Higher
Power density	Higher	Lower
Cold start	Yes	No

Water management	Complex	None

The temperature is one of the significant parameters when we define the characteristics of one PEMFC. Owing to its specific work temperature, the performances and requirements vary accordingly. (See Table 2)

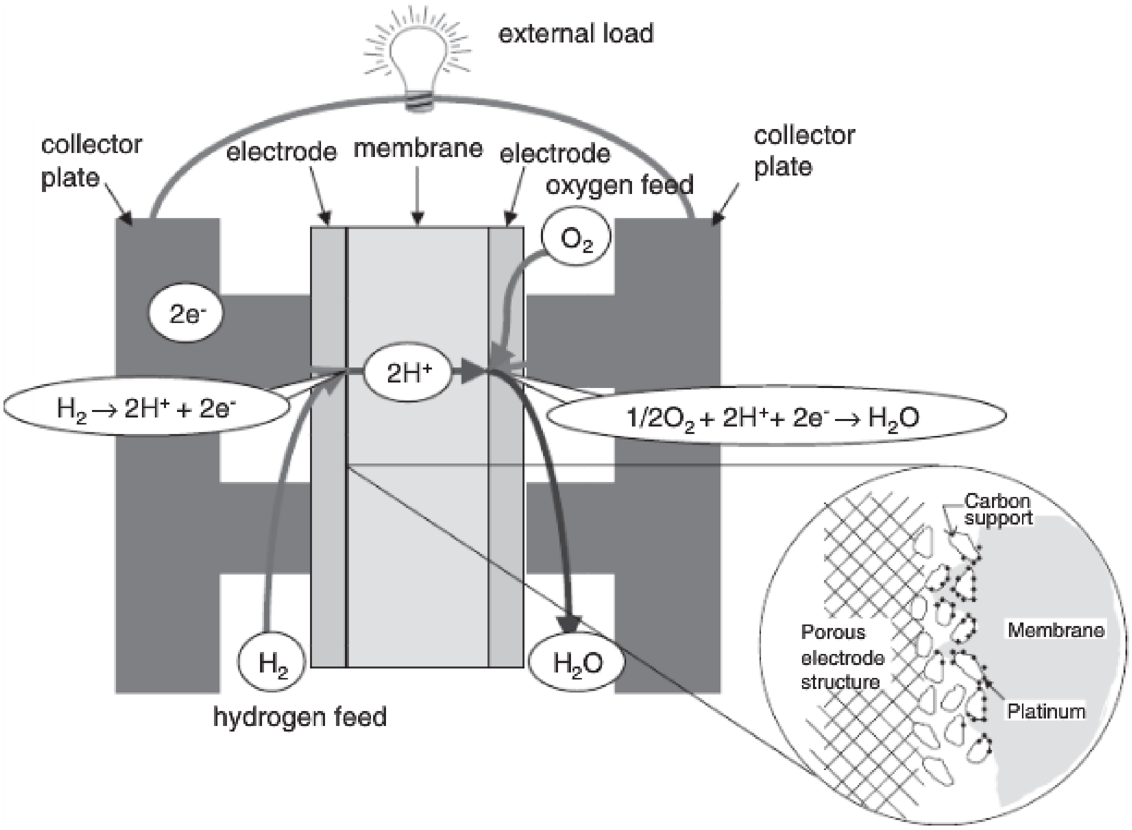

Figure 5. The basic operation principle of a PEM fuel cell. (Barbir 2013.)

Polymer membrane is the heart of a PEM fuel cell. It has some unique capabilities. One capability is impermeable, but it conducts protons so it also has another name proton exchange membrane. Membrane is squeezed between the two porous acts as electrolyte, conductive electrodes. These electrodes are typically made of carbon cloth or carbon fiber paper. At the interface between the porous electrode and the polymer membrane is a layer with catalyst particles that typically platinum supported on carbon (Barbir 2013). Hydrogen gas is fed from one side of electrode to fuel cell and it splits to protons and electrons. Protons transfer through the proton exchange membrane (PEM) and electron transfer through an external electrical circuit and then come back to the other side of the membrane. Oxygen gas is fed from another side and it combines with the protons and electrons at the catalyst sites between the membrane and the other electrode. Water is created in the electrochemical reaction and then pushed out of the cell with unused oxygen.

2.3.1 Components of PEMFC

A basic schematic of a PEMFC is provided in Figure 6 below:

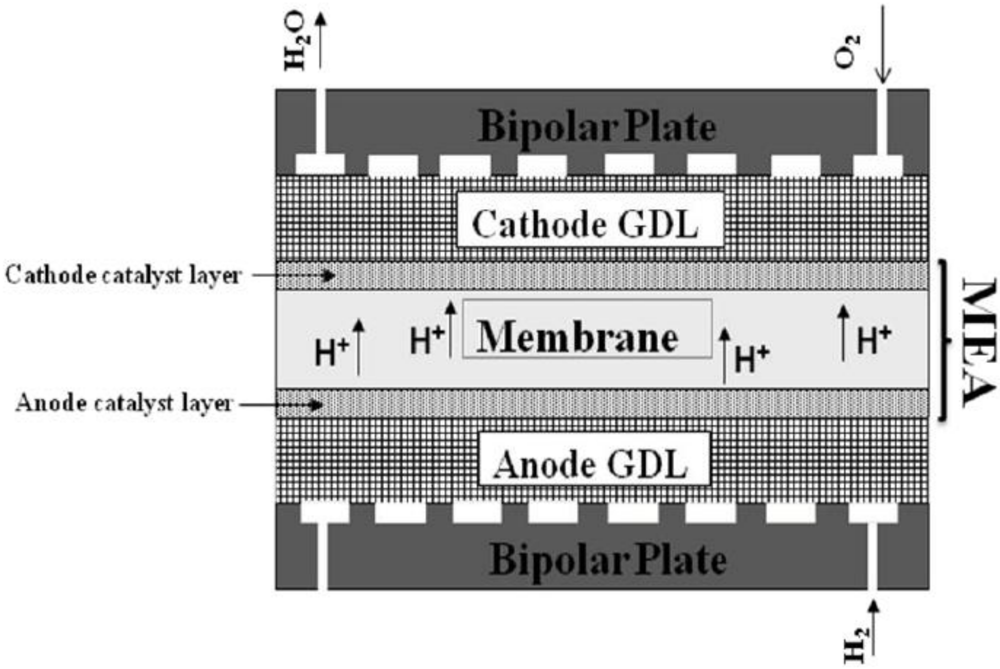

Figure 6. Basic schematic of a proton exchange membrane fuel cell. (Maiyalagen & Pasupathi 2010.)

Bipolar Plate

Bipolar plates are made up of electrically conductive carbon or similar plate and are vital components. Fine grooves are cut in their surface to allow fuel and oxidant to pass and be supplied to the electrodes that removes reaction products, collects produced current and provides mechanical support for the cells in the stack. Bipolar plate accounted for more than 60% of the total weight and 30% of the total cost of a PEMFC. (Fuel cell market.)

Figure 7. One Bipolar plate. (Fuel cell market.)

GDL (gas diffusion layer)

The most commonly used GDLs are carbon paper and carbon cloth. Homogenized, the gas follows to the catalyst layer. It controls water flow to maintain water content of a cell suitable. It keeps some water on surface for conductivity through the membrane. It transfers heat during cell operation: it provides enough mechanical strength to hold membrane electrode assembly from extension caused by water absorbance. (Benziger Group.)

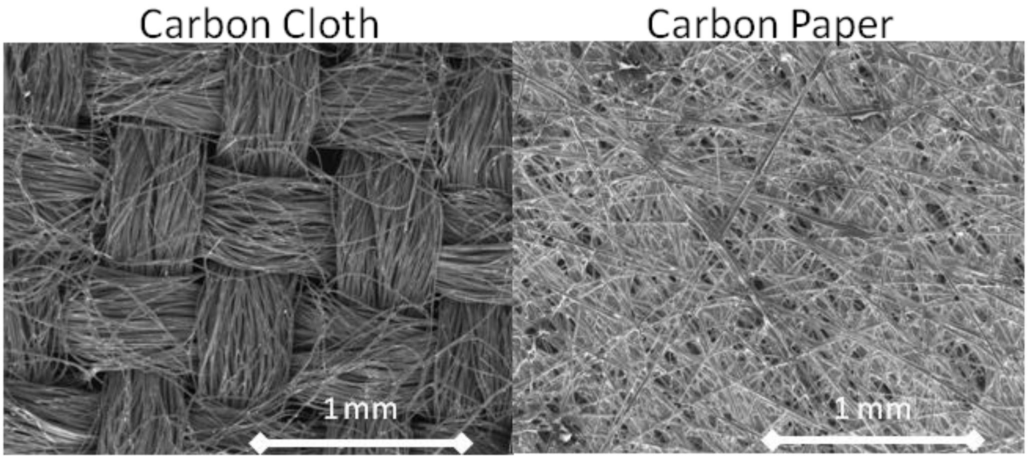

Figure 8. Gas diffusion layer. (Benziger Group.)

Catalyst layer

The membrane is coated on both sides with a thin catalyst layer that consists of micro scale carbon particles each supporting nanoscale platinum catalyst particles all loosely embedded in a matrix of ionomer. This catalyst-coated membrane is the MEA. The ionomer microstructure and ionomer-catalyst layer interface are important factors in the performance of the fuel cell. (Witinski.)

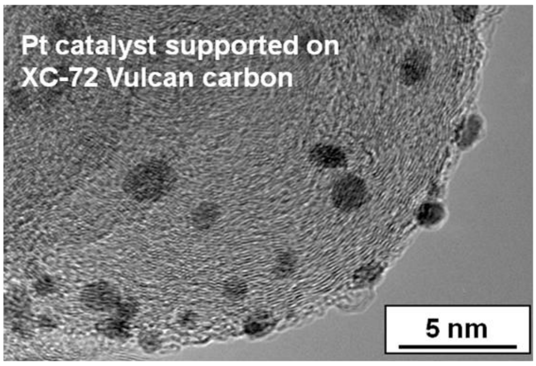

Figure 9. Catalyst layer. (ORNL.)

Membrane

In the PEMFC, a proton exchange membrane is used as the electrolyte, allowing hydrogen ion to move through it. The proton exchange membrane fuel cell (PEMFC) uses a water-based, acidic polymer membrane as its electrolyte, with platinum-based electrodes. (Witinski.)

3 Air Pollution Situation in China

To promote the FCV project, one of the most decisive motivations for us is the current air quality condition in Beijing. As the capital of our country, Chinese do not expect to leave a “foggy image” to the foreign visitors and our next generation. Therefore in this chapter the authors will find out what exactly brought this pollution to the city and its residences. Accordingly, the solutions will be given as well.

Figure 10. Took the exact same pictures in Beijing every day for year 2013. (Zhou 2014.)

The conclusion can be easily observed from Figure 10. Almost for half of the year 2013 Beijing was blanketed by a thick mist, and the residents suffered from what the soaring economy brought to them. Actually after 2012, one meteorological word became more frequently mentioned by the Chinese: Haze. After the “continuous foggy weathers” having its redefinition as haze, people’s awareness towards their surroundings unprecedentedly rose.

3.1 Air Pollution Level

The most officially used parameter to estimate the air pollution level is PM2.5. PM means Particulate Matter, is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Particles less than 10 micrometers in diameter (PM10) pose a health concern because they can be inhaled into and accumulate in the respiratory system. Particles less than 2.5 micrometers in diameter (PM2.5) are referred to as "fine" particles and are believed to pose the greatest health risks. Because of their small size (approximately 1/30 the average width of a human hair), fine particles can lodge deeply into the lungs. (EPA United States Environmental Protection Agency.)

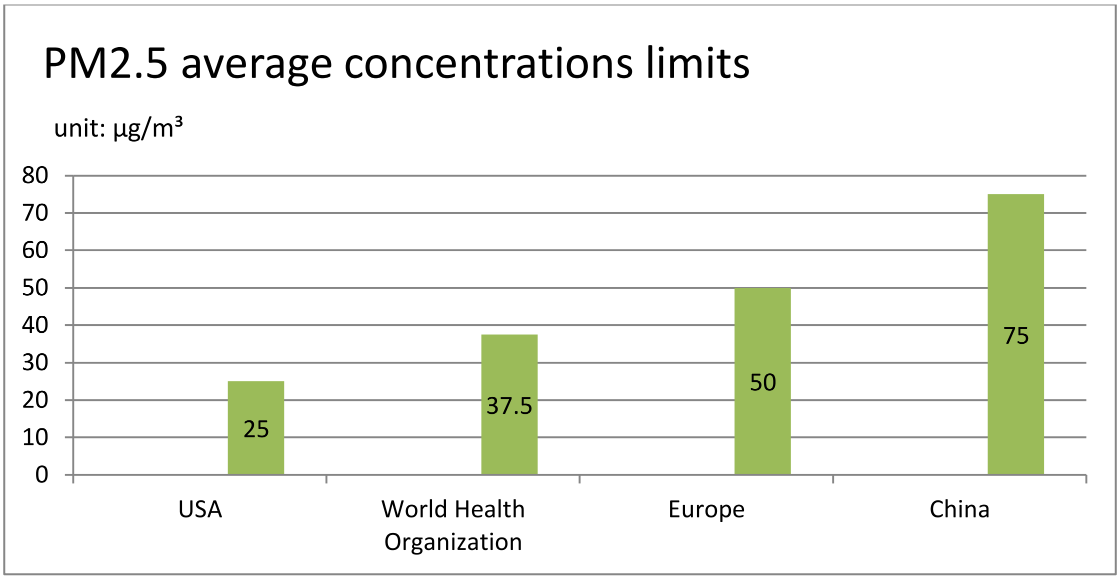

Figure 11. PM2.5 average concentrations limits. (NAAQS GR3095-2012.)

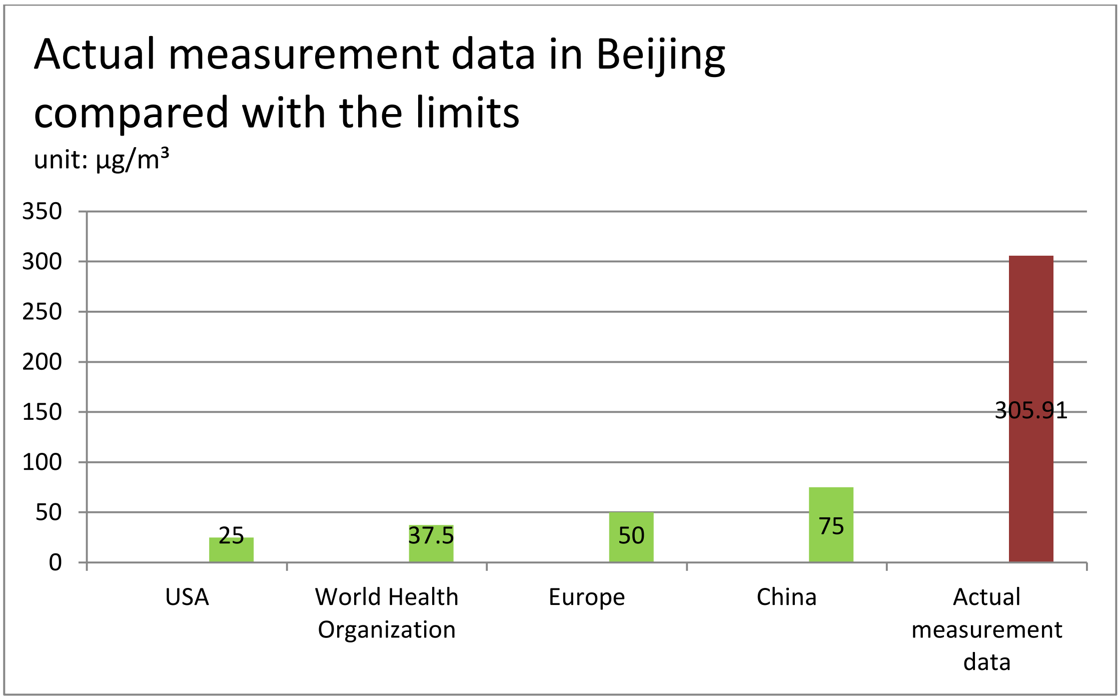

Figure 12. The Actual measurement data in Beijing compared with the limits.

Figure 11 was detected by Ambient Air Quality Standards GR3095-2012 which presents to us what is the PM2.5 average concentration limits. USA is 25 µg/m³, World Health Organization is 37.5 µg/m³ and the Europe is 50 µg/m³. Based on the Chinese population and economy development priority, the government set down the limits of 75 µg/m³ for PM2.5, which is as shown even three times greater than in the USA. However, the limits for China existed just in name only. From Figure 12 the actual measurement data for PM2.5 in Beijing reached up to 305,91 µg/m³, which is astonishing four times above the limits that we set by ourselves.

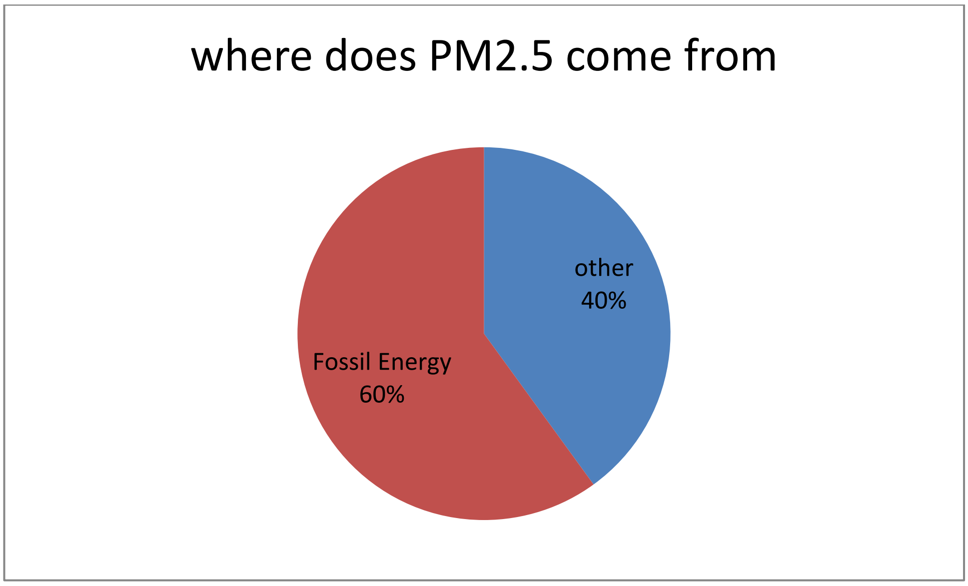

Figure 13. Where does PM2.5 come from. (Chinese Academy of Sciences Institute of Atmospheric Physics; Environmental Science and Engineering, Tsinghua University; Department of Environmental Sciences, Peking University.)

Formed from volcanic eruption and forest fires, PM2.5 has previously existed on the earth before the human civilization. After the human civilization began to exist, the increasing concentrations of PM2.5 were mainly caused by human activities. The wide use of coal brought “great smoky” incident to the UK and Germany, and the Petroleum Age also led to large-scale air pollution in the USA and Japan. Currently there are many developing countries still in their progress of industrialization with speeding up steps. China as the fastest growing developing country, leads at the fossil fuel combustion as well. From Figure 13, 60% of PM2.5 are produced through burning fossil fuel. Meantime the largest proportion of the burning fossil fuel in China is coal.

3.2 The Culprit of PM2.5: National Case

As illustrated in Figure 14, from the year 2000 China’s total consumption of coal progressively approached the total consumption of the rest countries around the world. And this upward tendency nearly reached as equal as the global coal consumption till the year of 2011. Coal already accounts for 20% of global greenhouse-gas emissions, making it one of the biggest causes of man-made climate change. That combined with the direct damage that air pollution caused by coal combustion does to human health, there’s a reason why some have called coal the enemy of the human race (Time 2013).

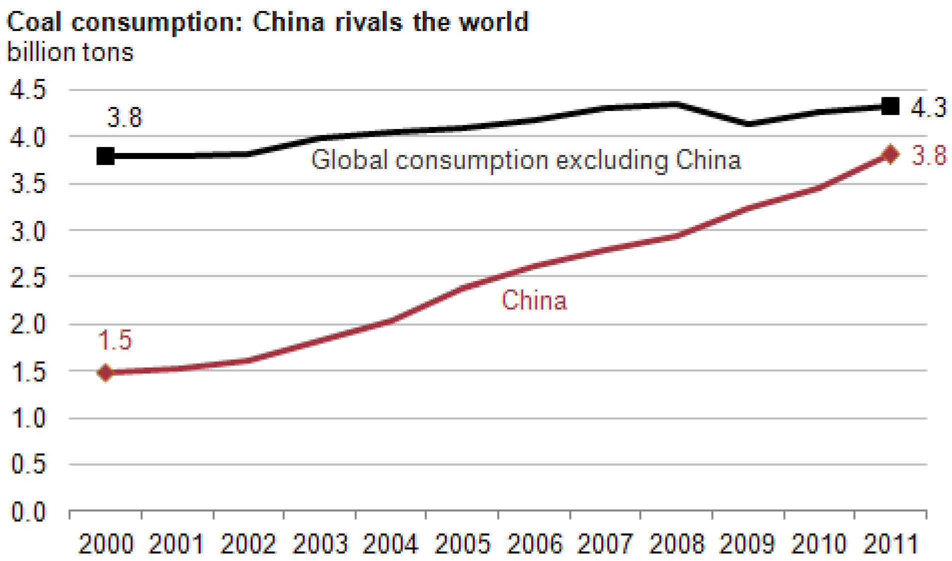

Figure 14. Coal consumption of China. (Time 2013.)

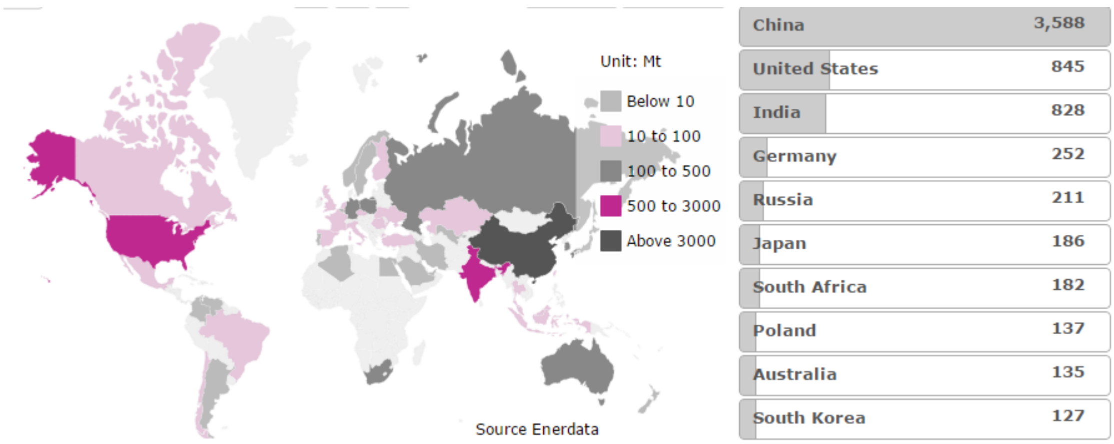

Figure 15. Coal and lignite domestic consumption in 2013. (Enerdata 2014.)

When comparing the number 3588 and 845 in Figure 15, we can work out the difference that one is over four times than the other one. Except the vast difference between China and the United States in the aspects of coal consumption, the authors suppose there are no more examples which can show such a wide gap between the first ranking and the second.

However, not solely owing to the tremendous amount of coal consumption, the quality of coal even has much severer influence on air pollution incident. In China, the coal that factories use for burning is not high-quality pure coal, which is directly resulting in more poisonous emissions during their combustion process. The pre-cleaning process is one efficient way and can largely reduce the later toxic particles emissions. But owing to the costly input of cleaning technology, nearly all Chinese factories would not adopt this method to their production lines. Moreover, for example, in China the density of PM2.5 in winter is 25 times greater than the density in summer since low quality coal is widely burned for household heating. Intending to solve this problem, authors advocate building a CPP/ CHPP which integrate washing, sorting and processing the coal before its entry to the market. After the impurities are removed from coal, both the quality and value can increase substantially, meanwhile their transportation cost will lower simultaneously.

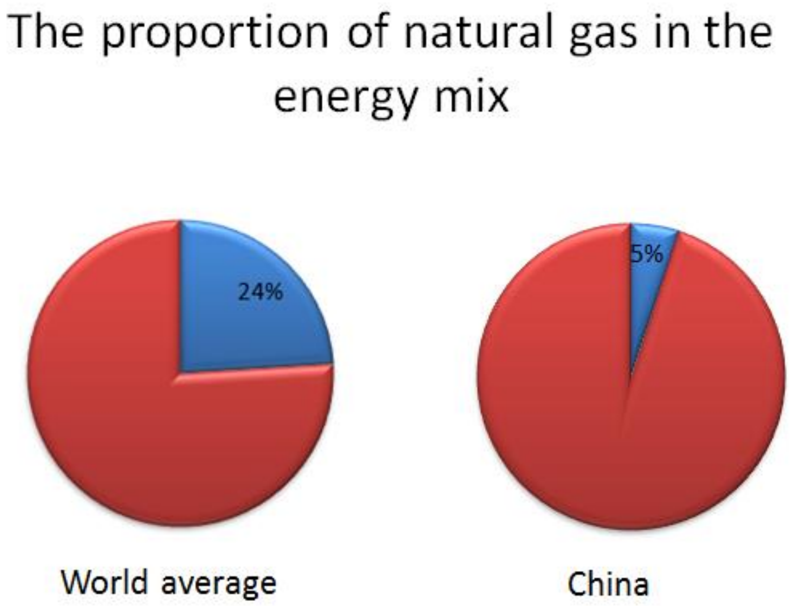

Figure 16. The proportion of natural gas in the energy mix between China and world average.

In Figure 16, when compared with the world average 24% of natural gas consumption in the whole energy structure, the China just takes advantage of this cleaner fuel for 5% of all the energy combusted. The dependency of China on the coal directly unbalances the fuel structure and leads to more poisonous emissions to form the “hazy dome” above Beijing. The exploitation for both natural gas source and market should be encouraged by the national and local governments. In 19th century London, the industrial revolution also caused the famous air pollution event — The Great Smog. Appendix 2 shows the obvious change of solid fuels’ proportion. Therefore their experience in how to change the fuel structure can be used by Chinese government for reference.

Last, the ambiguous statement in law and lack of tougher enforcement of the existing restrictions are also the reason for the serious pollution situation. The enforcement of the environmental protection regulations are always in a losing battle against the economic development priority. Moreover, the corruption between enterprise and government negates the restrictions at times.

Summarizing, the five biggest problems facing our air pollution in China at this moment are:

- Tremendous Consumption
- Unbalanced Fuel Structure
- Poor Quality of Coal
- Lack of Pre-cleaning Process for Coal
- Emissions Control

3.3 The Culprit of PM2.5: Beijing Case

Described by Figure 17, from the year 2002 the sales of automobiles in China kept its steeply upward tendency, and started to boost from 2009. Correspondingly, the sales of automobiles in Beijing were even above the national average level, and the gap between them appeared to be continuously enlarging. In accordance with statistics, Beijing city currently has roughly 200 cars per kilometre — the same traffic density as LA (The Wall Street Journal 2013).

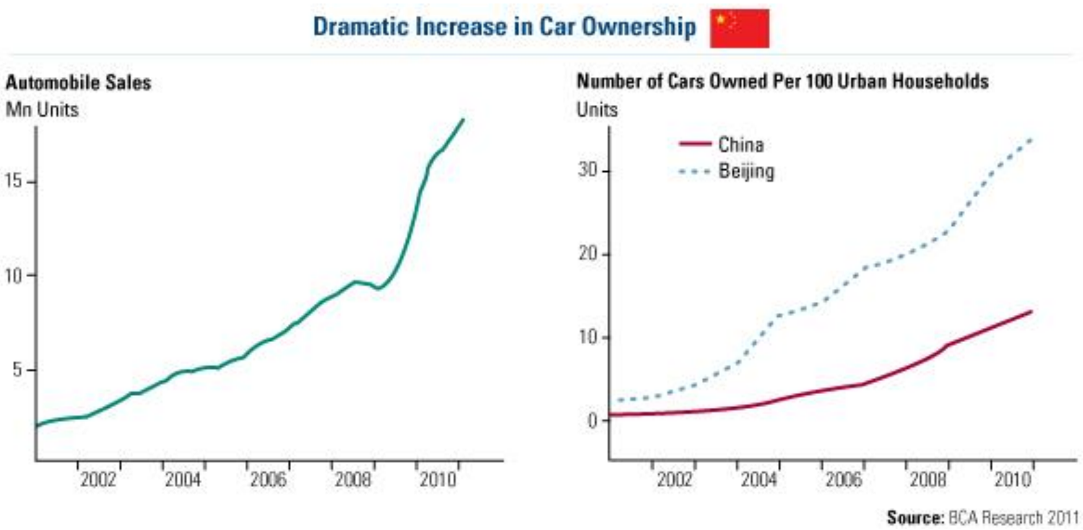

Figure 17. Vehicle ownership increase in China and in Beijing.

Between 2005 and 2030, China's car market is expected to grow tenfold, which will drive up demand for diesel and petrol from 110 million to 500 million tons. (Watts 2009.)

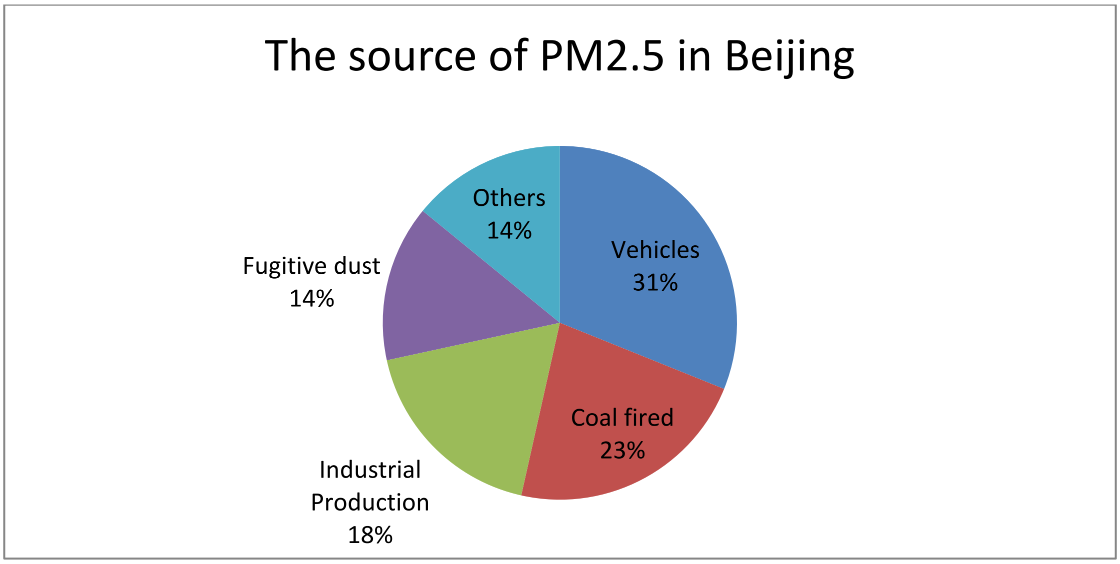

Figure 18. The source of PM2.5 in Beijing. (Beijing Municipal Environmental Protection Agency.)

As shown in Figure 18, the first pollution source of PM2.5, 31% of the total, is vehicles in Beijing. In the year of 2010, 800,000 new cars were added to streets only in one year. China only has about 3% of the world's vehicles, but accounts for 21% of the world's traffic fatalities (Wired Mag 2007).

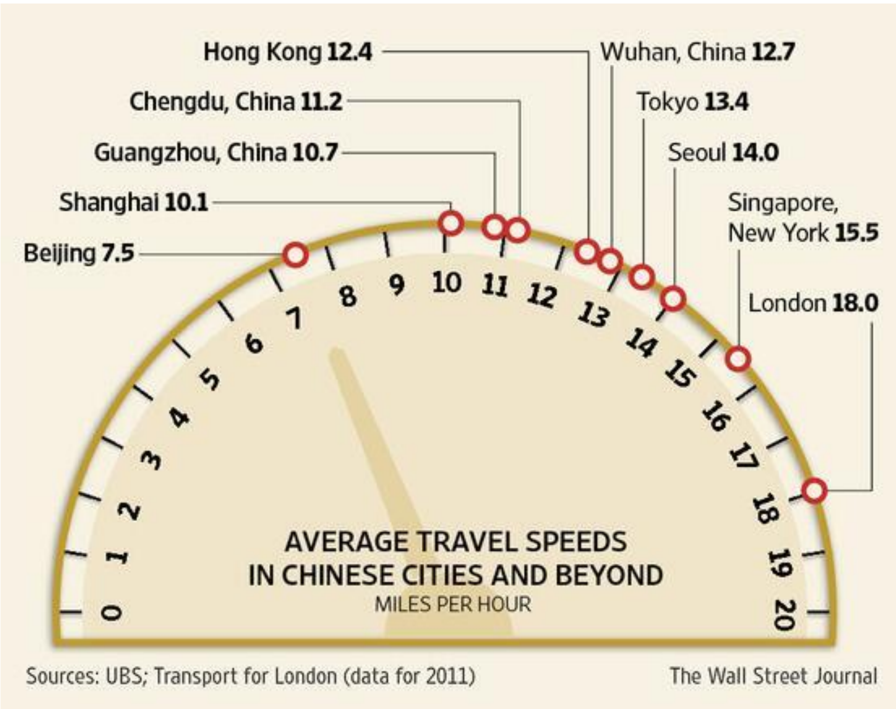

Figure 19. Average travel speeds in Chinese cities and beyond. (miles/ hour)

In Figure 19, as the Wall Street Journal reports, Beijing's average travel speed is only 12.1 kilometres per hour (7.5 miles per hour). That is to say the stop-and-start traffic means alternating between braking and accelerating. That burns more gas, spewing more toxic fumes into the air.

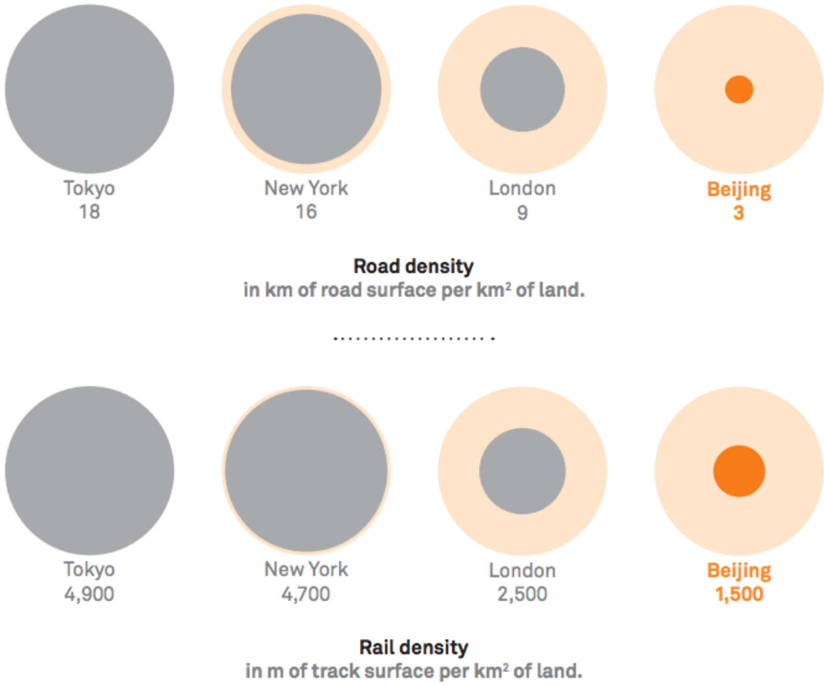

Figure 20. Road density and rail density. (Aecom Global Cities Institute.)

Here Figure 20 shows road density and rail density in several cities. The population of Beijing is around 19 million. But the road density is only three persons in km of road surface per km^2 of land. Compared with other big cities, it is much smaller density. Then in rail density we can see that Tokyo is at the top – 4900 persons in meter of track surface per km^2 of the land, it is over three times greater than Beijing. The data introduced by Beijing Transportation Research Centre shows that 44% of people in Beijing use car under the distance of 5 km, 12% of people use car in 2 km and 7% people use car just between the length of 1 km. People do not use public transportation as frequent as in other big cities and they prefer to drive rather than walk even to the destination nearby.

To sum up, the five biggest problems facing the severe air pollution in Beijing at this moment are:

- Rocketing Amount of Vehicles
- Heavy Traffic Jam
- Lacking Infrastructure for Pedestrian
- Inconvenient Public Transport System
- Lack of Awareness about Environmental Protection

From all of the above statistics analysed by the authors, it seems that promoting widely the FCV is one efficient and practical way to blow the “haze dome” away from Beijing.

4 Fuel Cell Applications

Fuel cells can generate electricity from a few watts to hundreds of kilowatts. For that reason they may be used for almost every application that can employ electricity as their power. Authors' viewpoint hereof is that the application of fuel cell can be sorted into three types in accordance with its functionality: **Portable, Stationary and Transport.**

Portable fuel cell is defined as those which are designed to be moved. These include military applications (portable soldier power, skid mounted fuel cell generators etc), Auxiliary Power Units (APU) (e.g. for the leisure and trucking industries), portable products (torches, vine trimmers etc), small personal electronics (mp3 players, cameras etc), large personal electronics (laptops, printers, radios etc), education kits and toys. To power this range of products, portable fuel cells are being developed in a wide range of sizes ranging from less than 5 W up to 500 kW. Portable fuel cells typically replace or augment battery technology and exploit either PEM or DMFC technology. (Fuel Cell Today 2013.)

Stationary fuel cell is defined as units which provide electricity (and sometimes heat) but are not designed to be moved. These include combined heat and power (CHP), uninterruptible power systems (UPS) and primary power units. (Fuel Cell Today 2013.)

Fuel cell for Transport is defined as any units that provide propulsive power to a vehicle, directly or indirectly (i.e. as range extenders). This includes the following applications for the technology (Fuel Cell Today 2013):

- Forklift trucks and other goods handling vehicles such as airport baggage trucks etc.
- Two- and three-wheeler vehicles such as scooters
- Light duty vehicles (LDVs), such as cars and vans
- Buses and trucks
- Trains and trams
- Ferries and smaller boats
- Manned light aircraft
- Unmanned aerial vehicles (UAVs) and unmanned undersea vehicles (UUVs), for example, for reconnaissance

4.1 Why Fuel Cell Vehicles?

Some of those application specific requirements and relative design variations are discussed in this chapter on account of the Beijing Project we aimed at.

Created during the 1990s and developing in the 21st century the fuel cell vehicle branch is showing year-on-year growth, with more prototypes being unveiled and more projects being deployed in market. The main motivators for development of automotive fuel cell technology are these: vehicles’ efficiency, low or zero emissions, and fuel that could be produced from domestic sources rather than imported. The major market barriers are the high capital cost and the availability and cost of hydrogen.

	Automotive	Stationary (Primary Power)	Stationary (Backup Power)
Power output	50 100 kW	1 10 kW & 200 kW	1 10 kW
Fuel	Hydrogen	Reformate	Hydrogen
Life (operational)	5000 hours	>40,000 hrs	<2000 hrs
High efficiency	Critical	Critical	Not critical
Instant start	Very important	Not important	Very important
Output mode	Highly variable	Variable	~Constant
Operation	Intermittent	Constant	Intermittent
Preferred voltage	>300 V	110/220 VAC	24 or 48 VDC or 110/220 VAC
Heat recovery	Not needed	Very important	Not needed
Water balance	Very important	Very important	Not critical
Size and weight	Critical	Not critical	Not critical
Extreme conditions	Critical	Not critical	Important
Cost	<$50/kW	<$1000/kW	<$5000/kW

Figure 21. Summary of Market Requirements for Fuel Cell Systems. (Barbir 2013, 374.)

4.1.1 Efficiency

The efficiency of an engine is measured by specific fuel consumption (g/kWh):

$$f_c = \frac{3.6 \times 10^6}{\eta_{sys} H_{LHV}} \qquad (1)$$

Where:

$$1kWh = 3.6 \times 10^6 J$$

H_{LHV} = lower heating value of fuel (kJ/kg)

η_{sys} = the total efficiency of the fuel cell vehicle engine system, comprising the vehicle fuel cell system efficiency, traction efficiency (typically about 93%), and electric drive efficiency (typically 90% or higher).

The f_c value of a gasoline internal combustion engine at its most ideal condition is about 240 g/kWh (Vielstich, Lamm, Gasteiger & editors 2003, 693-713), which corresponds to the system efficiency of 34%. Diesel engines have a higher efficiency of about 40%. A fuel cell engine at its most ideal condition may have the efficiency of above 50%, corresponding to the f_c value of below 60 g/kWh. (Note: based on energy lower heating value, the energy of 1 gram of hydrogen contains of what 2.73 g of gasoline contains.)

However, through the comparison above, we still cannot come to the conclusion that the fuel cell trumps the internal combustion engine. Since these two technologies are poles apart, they have intrinsically different efficiency power characteristics.

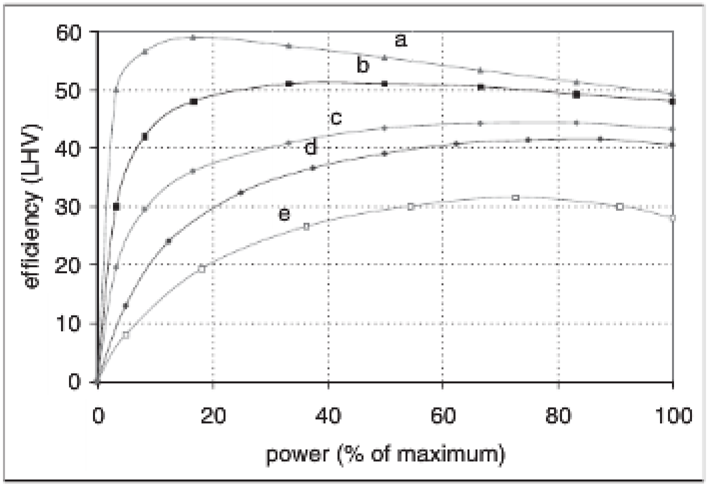

Figure 22. Comparison of the efficiency of fuel cells and internal combustion engines: a) fuel cell system operating at low pressure and low temperature; b) fuel cell system operating at high pressure and high temperature; c) fuel cell system with an onboard fuel processor*****; d) compression ignition internal combustion engine (diesel); e)spark ignition internal combustion engine (gasoline). (Vielstich, Lamm, Gasteiger & editors 2003, 714-724.) (Hoogers, editors 2003.)

***onboard fuel processor:** Systems which can convert liquid fuels such as gasoline and diesel to hydrogen while hydrogen infrastructure and storage are investigated.

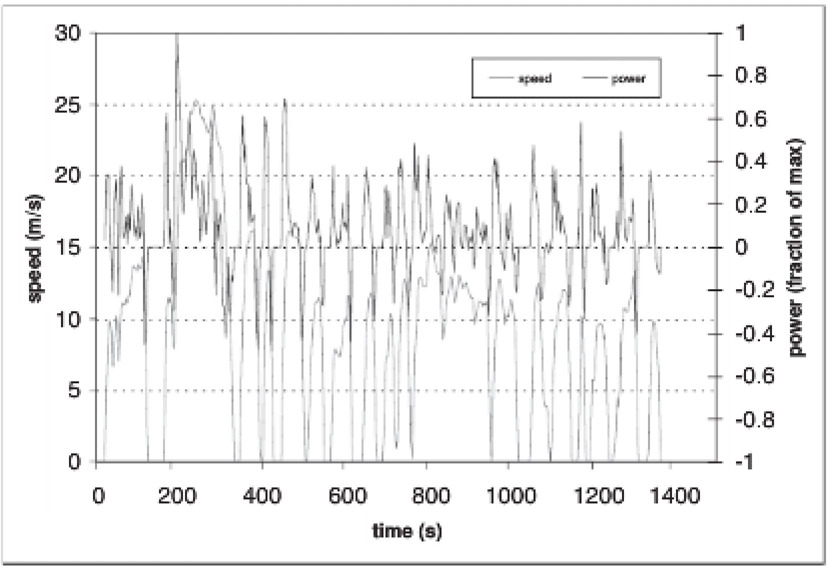

Figure 23. U.S. EPA Urban Dynamometer Driving Schedule. Average speed 8.7 ms^{-1}, average power 12% of maximum power. (UDDS.)

A fuel cell system has its maximum efficiency at partial load, whereas an internal combustion engine can attain its maximum efficiency near its maximum power (see Figure 22). Because of this, the efficiency of a hydrogen fuel cell system in a typical driving schedule (like what shown in Figure 23), where most of the time an engine runs at partial load, can achieve about twice that of an internal combustion engine.

4.1.2 Emission

Another reason for the fuel cell vehicles appearing to be a promising alternative is its low or zero emissions. A hydrogen fuel cell does not generate any pollutants. The only by-product is pure water, which leaves the system as both liquid and vapour. If liquid fuel (like gasoline and diesel) is utilized, the fuel cell system will have some emissions during its hydrogen conversion process. Those are still much lower than the emissions from an internal combustion engine.

In order to comprehensively analyse the emission, the concept of entire life-cycle is introduced. That is to say, if hydrogen is generated from fossil fuels, the emissions from the reforming process should also be taken into account.

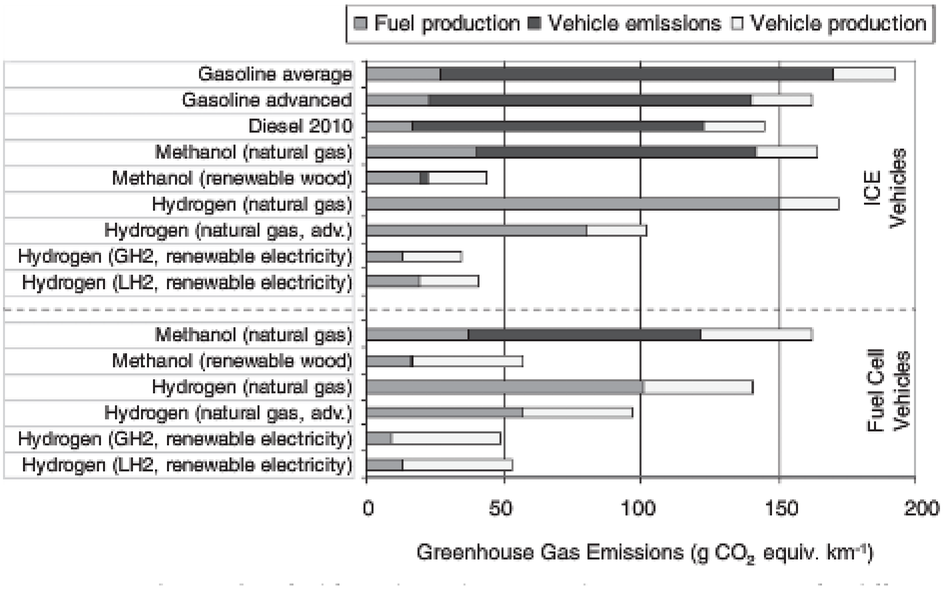

Figure 24. The results of a life-cycle analysis: greenhouse gas emissions for different power train and fuel options. (Vielstich, Lamm, Gasteiger & editors 2003, 1293-1317.)

In Figure 24, the vehicle emissions take the biggest proportion of traditional engine total emissions, whereas there are no emission from fuel cell hydrogen engine. So, the fuel cell vehicles generate clearly less greenhouse gases than the gasoline or diesel powered internal combustion engine vehicles. The lowest emissions in Figure 24 were ascribed to the hydrogen powered internal combustion engines. The cause was attributed to the higher emissions from the fuel cell vehicle production.

4.1.3 Cost

Fuel cell vehicles are still manufactured on a prototype level, which directly leads to its less competitiveness on cost in relation to traditional engines. However, studies have shown the fuel cells could be produced cost effectively, assuming mass production manufacturing techniques are applied.

	2012 Automotive System					
Annual Production Rate	**1,000**	**10,000**	**30,000**	**80,000**	**130,000**	**500,000**
System Net Electric Power (Output)	80	80	80	80	80	80
System Gross Electric Power (Output)	88.24	88.24	88.24	88.24	88.24	88.24
Fuel Cell Stacks	$11,731.03	$3,296.20	$2,349.26	$1,963.46	$1,843.95	$1,613.36
Balance of Plant	$5,527.67	$3,328.28	$3,220.79	$2,671.34	$2,468.38	$2,044.57
System Assembly & Testing	$145.13	$100.62	$98.90	$98.69	$98.24	$98.25
Total System Cost ($)	$17,403.83	$6,725.10	$5,668.96	$4,733.49	$4,410.57	$3,756.18
Total System Cost ($/kW$_{net}$)	$217.55	$84.06	$70.86	$59.17	$55.13	$46.95
Total System Cost ($/kW$_{gross}$)	$197.23	$76.21	$64.24	$53.64	$49.98	$42.57

Figure 25. Detailed system cost for the 2012 automotive technology system. (James and Spisak 2012.)

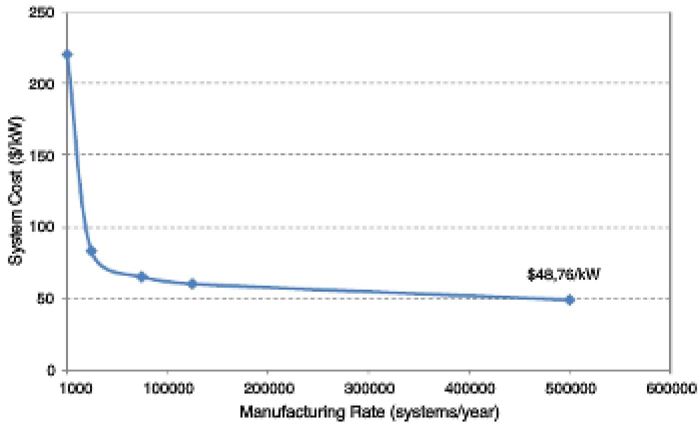

Figure 26. Fuel cell system cost estimates as function of manufacturing rate. (James 2012.)

Figure 25 is the detailed system cost for the 2012 automotive technology system. As what it illustrates, the most costly process of the whole FCV system is the fuel cell stacks. This is also the key link of total cost which would plunge as the shooting up of production rate.

Figure 26 demonstrates that for a manufacturing rate of 500,000 units per year the achievable manufacturing cost with state of the art technology (2012) would be $49 per kW. (James 2012.)

The main cost components are the catalyst (precious metal, Pt, or Pt alloys) and the ionomer membrane.

Table 3. The major 2 high cost components in fuel cell, assuming power density of 0.7 W cm^2.

	UNIT PRICE	COST PER KILOWATT
Platinum loading	0.3 mg per cm^2, $50 per gram	$40
Ionomer membrane	$500 per m2	$50–70

To be competitive with gasoline engines, the cost targets should be in the range of $35–50 per kilowatt. Therefore it requires improvements in:

- fuel cell performance (more watts per unit active area)
- reduction in catalyst loading or alternative, less expensive catalysts without sacrificing the performance
- novel and less expensive membranes

Based on Aalto University's research (Kallio 2015) concerning the electrocatalyst development, researchers have succeeded in developing a substitute to platinum that is cheap and effective. The new electrocatalyst is made of iron and carbon. And the same efficiency that was achieved with platinum can be obtained with this less expensive material.

Therefore the FCV is chosen by the authors as the most suitable transport vehicle to be promoted to Chinese market. Then in the next chapter we will study what the markets are like nowadays in China.

5 “The Wild East” — Chinese Market

With average annual growth rate 15%, China undoubtedly is becoming the world’s largest potential market for automobiles. Many car manufacturers have already fixed their eyes on the thriving Chinese market. The opportunities are endless on this new frontier, but there are also innumerable pitfalls for the unwary. This is why the authors compare China, “The Wild East”, to the Wild West of Hollywood movies. When we enter into an emerging market, the right one who can open the door must be the one who knows the story behind the door.

Therefore, the Chinese market characteristics and the fuel cell market tendency will be studied in this chapter.

5.1 Chinese Market Characteristics

According to Björkstén (2010, 12), China is such a large, complex, and dynamic marketplace that you need to be even more vigilant and astute than on more mature markets. Why the Chinese market is so different in westerners’ eyes? From Luo’s (2002) summary of commonalities among the emerging market, may answer this question in some measure.

First, legal infrastructure, including legal system development and enforcement is generally weak. “People”, rather than laws themselves, still play a significant role in shaping commercial activities. They have unique commercial practices and business culture that are people-oriented and socially-embedded. As such, bribery and corruption are evidently more pervasive and interpersonal networking is often necessary for business activities.

Second, factor market such as capital market, labour market and information market are still intervened by governmental institutions.

Third, fast economic growth is primarily driven by strong market demand, deregulated industries and foreign investment participation. All of these thus increase the uncertainty and volatility of the growth.

Fourth, the strong demand is mainly contributed by increased individual incomes (especially middle-class), previous stifled demand by government control and large population.

Fifth, MNCs can easily get first-mover advantages and opportunities in emerging markets, but meanwhile always have to face competitions from other foreign companies, and local companies with high imitation ability.

Overall, the government is one significant part in shaping business competitiveness. The time spent cultivating local ties can yield higher returns. At the national level, it is also important that companies demonstrate a strong alignment between their corporate strategies and the Chinese state's development priorities and goals.

5.2 China Supporting Policies

At the early introduction stage of the FCVs, the demand of individuals or a fraction of the consumer group cannot be seen as the bellwether of the market. Most of them have no relevant experience of this technology previously and therefore what is their real demand turns out to be vague. On the contrary, the state policy or the demand from the government should be accorded para-mount importance when considering the market tendency.

China started to promote PEMFC R&D in the mid-1990s under its 863 Program, which is the government's multiyear high technology development program. During the early 2000s, China pursued an ambitious plan to establish PEMFC technology for transport applications, particularly for passenger cars and buses. Then China chose to boost the budget of three major national programs to promote PEMFC and FCV technologies. In effect, this refocused the goals of the 863 Program, the 973 Program and the Torch Program. (Behling 2012.)

- **Two consecutive 5-year plans under the 863 Program.** China placed major emphasis on the development of PEM fuel cell cars and buses under the 10th 5-year plan (2001－2005) and the 11th 5-year plan (2006－2010), primarily through the 863 Program. The 10th 5-year plan allocated $106 million for fuel cell development. The 11th 5-year plan further stepped up funding. A total of $172 million was allocated for energy technology development.
- **The National Hydrogen Energy Project 973.** With a budget of approximately $3 million from 2000 to 2005, Project 973 promoted basic research to strengthen fundamental R&D, notably with regard to the production, storage, and distribution of hydrogen and fuel cells.

- **The Torch Program.** Torch was China's most important high-technology industry program. The program would fund individual organizations and their efforts to develop and commercialize new high-technology products, including fuel cells and FCVs.

Summarizing, the Chinese effort to develop PEMFC and FCVs was massive, systematic and broad. Any notable research institution, university, or company with fuel cell development activities was provided with long-term funding by the government. In total, at least 23 fuel cell cars were developed and at least 19 fuel cell buses were developed by the end of the 2000s. It is not difficult to see that enormous sum of funding must have been poured to PEMFC and FCV development. Meanwhile, the government also provided specific direction and guidance to fuel cell developers, which they were obligated to implement under the national programs. While this direction was logical and reasonable, it would be highly unusual if any Western government were to apply such management tools to private-sector industries.

Thus after realizing the typical characteristics of Chinese market, the authors will plot the implementation stage of the suggested FCV project.

6 FCV Introduction Phase in China Market

At the early introduction stage of the fuel cell technology, the bus was chosen as the vehicle type for the Chinese market. One reason for this is the regularity of the bus service operation. It can make refuelling with hydrogen much easier. Another reason for this decision is the availability of space on the bus. Since there is enough room for fuel storage tank, then the requirement for the hydrogen compression pressure can be lower. Almost all the buses built today use 350 bar compressed hydrogen tanks. In addition, because hydrogen is much lighter than air, the preferable and safe position for gas cylinders is on the bus's roof. So it is also no need to take into account the allocation of the passengers' and the tanks' space. Lastly, fuel cell-powered buses deliver economic, operational as well as environmental benefits, when compared to traditional diesel or diesel hybrid systems. The major advantage is its zero emissions. This is particularly important in already densely populated and heavily polluted cities. The fuel cell buses could significantly reduce air pollutants such as nitrogen oxides, sulphur oxides and particulate matter.

According to the reasons above, the buses for city and regional transport are considered the most proper type of vehicles for an early market introduction of fuel cell technology.

Nevertheless, the cost and durability are the main obstacles for commercialization of fuel cell buses. Because of the smaller market demand, the mass production manufacturing techniques still cannot deploy. This directly brings about the cost of the bus engines per kilowatt to be somewhat higher than the cost of the automobile engines. Based on the heavy traffic jam situation in Beijing, the highly intermittent operation with many starts and stops also poses a challenge to fuel cell durability with current domestic technology. Although China has recently seen an unprecedented rapid development in fuel cell vehicles, it has failed to be comparable with Japan and Germany in terms of the technical maturity. Given China's lagging behind, the writers consider that a joint venture might serve as a shortcut of applying FCVs to China's market. A joint venture not only proves to be profitable for foreign vehicle manufacturers, but also helps promote instant development of FCVs in China.

6.1 Availability of the Joint Venture

The available foreign and Chinese automobile suppliers will be studied in this chapter.

Foreign Suppliers

Some of the prototypes are shown in Figure 27. Figure 28 presents characteristics of the most recent fuel cell buses developed and demonstrated all over the world. The providers mentioned in Figure 28 can be the potential foreign parties of the joint venture.

Figure 27. Some prototype fuel cell buses. (clockwise from top left: Hydrogenics Rampini, Van Hool A300L, APTS Phileas, Mercedes Citaro.) (Hy Web.)

Manufacturer	Model	Year	Passengers	Fuel cell	Provider	Batteries	Electric motor	H2 storage	H2 pressure	Status
Toyota/Hino	Blue Ribbon	2010	26	180 kW	Toyota	Ni-MH 84 kw	2x80 kW		350 bar	In service connecting downtown Tokyo with Haneda and Narita Airports
ISE Corp./ Wrightbus	Pulsar H	2010		75 kW	Ballard	Supercaps 2x85		6 tanks	350 bar	8 buses in operation in London
APTS	Phileas	2010		150 kW (130 net)	Ballard	Ni-MH 100 kW; supercaps 100 kW	240 kW	36.4 kg in 8 tanks (1640 l)	350 bar	2 buses at RVK (Cologne) and 2 at GVB (Amsterdam)
HAN Automotive	VDL Ambassador ALE 120-205/ 225	2010			Nedstack			3 tanks	300 bar	demonstration
SAIC	SWB6129FC	2010	49	80 kW net	Ballard	Li-iron-phosphate 100 kW				demonstration at EXPO 2010 Shangai
Fbus	Battery City Bus	2009	22	38 kW	Ballard	50 Ni-Cd (100 Ah)	130 kW	15.5 kg in 2 tanks (700 l)	350 bar	demonstration
VanHool	A300L new	2009		120 kW	UTC Fuel Cells	yes	2x85 kW		350 bar	12 buses for AC Transit (CA) 4 buses for CT Transit (CT)
Hyundai	Super Aero City	2009	28	200 kW (160 net)	Hyundai/ KIA	Supercaps 100 kW	3x100 kW	27.3 kg in 6 tanks (1260 l)	350 bar	test runs in Seoul and other Korean cities
Daimler AG	Mercedes Citaro E4	2009	77	150 kw (120 net)	AFCC	Li-Ion 250 kW		32 kg in 8 tanks (1435 l)	350 bar	small series

Figure 28. Fuel Cell Buses Demonstrated to Date. (Hy Web and Barbir 2003, 683-692.)

Chinese automobile enterprises

After looking through the research made by Oliver, Holweg & Luo, the authors categorizes the established Chinese automobile companies into three types according to their capital scale, production capacity, product ranges, and operation pattern.

The first type is the Chinese large-scale corporations. It is comprised of the Top Four automakers: Dongfeng Motor Corporation (DFM), FAW Group Corporation (FAW), Shanghai Automotive Industry Corporation (SAIC), and China Chang'an Automobile Group (CCAG). Furthermore, they are the only four Chinese automobile corporations which ascended to the "Fortune Global 500". Therefore as the first-movers, they lead other companies in their understanding and use of technology. They have strength to control some resources necessary for the automobile manufacturing. Also, they have already earned brand loyalty from Chinese automobile market. Their consumers tend not to spend time seeking information about other cars. In addition, all of them are state-owned, which is naturally supported by both central and local government.

The second type is the Chinese medium-sized automobile enterprises, such as Zhengzhou Yutong Group Company (Yutong), Beijing Automobile Works Company (BAW), Xiamen Golden Dragon Bus Company (Golden Dragon), Guangzhou Automobile Group Company (GAC). They have narrow but more specialized production lines. For instance, Golden Dragon and Yutong are both renowned for their bus and coach product. They have strong innovation ability and own many patents on the core technologies of bus manufacturing. Therefore, more efficient management system and high market share at bus manufacturing business are the two evident strengths they possess. From the authors' viewpoint, these medium-sized enterprises could be the most possible partner of the joint venture in spite of the smaller capital scale they have when compared with Top Four.

The last type is the Chinese small and medium private automobile enterprises. It includes Chery, BYD, Geely, Beijing Shiguang, Shenzhen Minghua Group Company, Shenzhen Wuzhoulong Automobile Company, WanXiang Group, and Tianjin Qingyuan Vehicle Company. Confined by the company scale, their investment on their product innovation is limited. Most of their value adding work is restricted to the process of assembly, which means the procurement of core components takes large proportion of their business operations. But meanwhile benefiting just from its small company scale, they are quite sensitive to respond to the market. Their efficiency of management, operation and the fund utilization are extremely high. What can be mentioned here is that these SMEs operate in close cooperation with the local government. For example, the Chery gained a bundle of subsidies and projects from the local government at their initial stage of development. In Wuhu city, nearly all the taxis were changed to Chery brand. The government also offered the subsidy to the consumers of Chery cars.

6.2 The Joint Venture

According to Porter's theory, there are three possible generic strategies applied in a company to achieve competitive advantages: cost leadership, differentiation and focus. To determine the right direction of the joint venture is especially essential for us while operating a new technological product in emerging market.

6.2.1 Cost Leadership

At the introduction stage, limited by low demand level of individuals, it is arduous to deploy mass production manufacturing techniques. Considering that the government procurement is still the largest purchasing power of FCV, all the effort aiming at cutting down the unit cost through the economies of scale will be seen as futility. Moreover, cost reduction of the input is also a long shot, because the component suppliers cannot achieve economies of scale either.

In the next 10 years, the target of cost leadership can be gradually accomplished. The China "New Energy Development Plan" distinctly pointed out that until the year 2020, the production volume of FCV should reach 5,000,000. At that moment, based on the increased order of FCV and components, the unit cost and the cost of input will be lowered by a wide margin. But even so, if combining with price strategy, this kind of FCV would expand their advantage and will be more preferred by consumers especially in the price-sensitive Chinese market. Therefore authors will enlarge on some strategies about enhancing the cost leadership edge of the joint venture's FCV.

Firstly, from the perspective of government, we find out that the profit margin of the joint venture FCV tends to be increased if:

- Government supports to build the industry alliance of FCV
- Government subsidizes the consumers of FCV, meanwhile cutting down subsidies of other type vehicles. According to the latest announcement of the government, the subsidy for each FCV user can range from 63000 to 108000 yuan. (approximately 9000 € to 15000 €)

- Government provides financial support such as fund, tax incentives and rent incentives to the joint venture
- Government sets down higher barriers for substitutes (such as diesel and gasoline engine vehicles) through new policy formulations
- Government accelerates the establishment of FCV industry standard, e.g. technology standard, the automobile emission standard and the patent application standard. Thus a harmony environment for development and innovation will be created.

Then from the perspective of the joint venture itself, comparing with lowering the price of FCV, car manufacturers should lay emphasis on how much added value they can bring to their users.

Based on the current traffic situation of Beijing, stricter controls had to be placed on purchase of new cars and licence for the cars. In Beijing, getting a car licensed is no easier than winning a lottery, with only 0.9% possibility. In consideration of the increasing purchasing power, this regulation runs absolutely counter to the market demand. Thus if the joint venture can be exempted from the government control, it would attract more individual user to buy their first FCV at once rather than waiting for the lengthy process of license for their brand new gasoline engine car. This kind of government support which is allowing a quicker process for the automobile license would be entirely possible if the joint venture is able to demonstrate a strong alignment between the corporate strategies and the Chinese state's development priorities and goals.

Another regulation issuing in Beijing since 2013 is the "odd-even" car ban. This restriction required alternate driving days for cars with even- and odd-numbered license plates in case of lingering haze. That is to say when the city issues a red alert for air pollution, an alternate-day driving system for odd- and even-numbered license plates will be employed to reduce air pollution. Thus assuming that the FCV can be exempted from Beijing alternate-day driving system restriction, this policy will undoubtedly bring a large number of clients to be early users of the FCV. Meanwhile because of zero emissions, the usage of FCV would not be inconsistent with what the "odd-even" car ban is aiming at either.

6.2.2 Differentiation

Combing the foreign leading technology and the Chinese local enterprise's indigenous advantage, this joint venture should set down differentiation as their major strategy direction. Compared with cost leadership, this more sustainable competitive advantage can be yielded from mainly two aspects: demand and supply.

Demand denotes understanding and matching what the customers need. At present, most residents in cities choose long-distance drive at weekends and during holidays. The distance for self-driving tour is normally over 300 km and the speed typically reaches up to 120 km/h on account of running on the highway. Further, people prefer a compact, convenient and low fuel consumption car from home to work at weekdays. Hence the FCV facing to Chinese customers should cope with above mentioned two situations easily. The FCV must be localized to accommodate Chinese user's habits. Moreover, for the joint venture it is not necessary to start from consumer researches, since all the recommended Chinese local car manufacturers have already over 10 years' experience dealing with Chinese customers. Anyone of them would perform satisfactorily in the process of localization.

Supply means identifying precisely the company's capacity to supply differentiation. With all of its top-tier universities conducting fuel cell research, China has a strong research base. So the first strategy for differentiation is to work in close collaboration with Chinese research institutes. Thus the joint venture can carry out the innovation to fulfil their customers' need better and at the same time with relatively low cost, because all the institutes conducting fuel cell research will receive funding from Chinese government. Some institutes and research companies that could establish the partnership with are listed in Appendix 1.

Secondly, the joint venture should provide the customers a more convenient access to their FCV than their competitors. One method for this strategy is to fully utilize the Chinese partner's ready-made distribution channels and service network. Many of the recommended Chinese car manufacturers have already built 4S shops covering all the first-, second- and third-tier cities to provide sale, spare components, service and survey of their automobiles. So the joint venture should develop and take advantage of these resources. The other method the authors provide is to cooperate with local car rental agency. As it is known to all, Beijing attracts more than hundred millions tourists from all over the world. With the same price level with the other traditional type cars, the available FCV for rental in the agency must be favored by the customer. This can be seen as the extension of the driving test service. However, considering that the differences between the FCV and the traditional type vehicles, the joint venture also should provide training for the staff of rental agency.

Lastly, signalling and reputation are crucial to the joint venture as well. For delivering the information of its safe, high-quality, practical, applicable FCV to the consumers, multi-approach promotion activities should be utilized simultaneously. For example, the joint venture can participate in sports sponsorship; collaborate with big scale business events and sponsor the television programs to raise their brand awareness in the publicity.

7 Conclusion

From the situation of Beijing's air pollution, one gained insight for authors into all the Chinese pollution is that China must start to carry out the revolution of its energy structure. The whole country should multiply the percentage of cleaner energy usage, with continuously added proportion of natural gas usage in energy mix, and gradually decreasing reliance on fossil fuels. Through benefiting from the experience of other countries in terms of energy structure change, the exploitation activities for both natural gas source and market should be encouraged and supported by the national and local government policies.

On the subject of current situation, the pre-treatment process for coal ought to be introduced to entire market. The CPP/ CHPP, which integrates washing, sorting and processing the coal, can be adopted before entering and selling in the fossil fuel market. Pre-cleaning and quality control will be seen as the two most efficient ways to purify the Chinese coal market. Meanwhile the government and municipality are supposed to enforce national standard for all industrial emissions. While fostering the clean technology project in factories, they should give strong backing and provide fund to those responders as well.

Furthermore the environmental restrictions concerning responsibility, enforcer and corresponding punishment must be defined clearly in its statements. The inspection organization for monitoring environmental law-enforcement agencies is required to be reinforced to prevent collusion between officials and enterprises throughout the energy market.

Regarding the discussion in this thesis concerning the new technology of FCV, it is undoubtedly one practicable solution for solving Chinese air pollution that is resulting from vehicle exhaust. Based on the form of joint venture that the authors recommend, several strategies are also given in accordance with the study on the availability of this business model. They are designed to widely help promote FCV and develop joint venture.

From the government perspective the strategies are:

- To build the industry alliance of FCV.
- To subsidize the buyers of FCV, with cutting down subsidies in respect of other type vehicles.

- To provide financial support such as fund, tax incentives and rent incentives to the joint venture.
- To set down higher barriers for substitutes (such as diesel and gasoline engine vehicles) through new policy formulations.
- To accelerate the establishment of FCV industry standard, e.g. technology standard, the automobile emission standard and the patent application standard. A harmonious environment for development and innovation accordingly ought to be created.
- To foster the FCV project through government procurement at its introduction stage.

From the joint venture perspective the strategies are:

- To demonstrate the strong alignment between the corporate strategies and the Chinese state's development priorities and goals.
- To focus on the adding value that the company's FCV will bring to buyers. Some examples like the company can apply for the exemption from government vehicle control and alternate-day driving system restriction.
- To localize the FCV to accommodate it to Chinese user's habits.
- To work in close collaboration with Chinese research institutes to achieve technical innovation in relatively low cost.
- To provide the buyers a more convenient access to their FCV by means of utilization of the Chinese partner's ready-made distribution channels and service network.
- To make the experience of FCV much easier and cheaper to the potential buyers through cooperating with local car rental agency.
- To raise the brand awareness in the publicity.
- To deliver the safe, high-quality, practical, applicable FCV image to the consumers.
- To continue improvements to accomplish cost leadership finally.

REFERENCES

Altenergymag. Different types of fuel cells. [Read: 10.3.2015]. Available: http://www.altenergymag.com/emagazine.php?issue_number=06.04.01&article=fuelcells

Barbir, F. 2013. PEM Fuel Cells - Theory and Practice. Elsevier. Online version available at: http://app.knovel.com/web/toc.v/cid:kpPEMFCTP3/viewerType:toc/root_slug:pem-fuel-cells-theory/url_slug:kt00ANQ3V2

Barbir, F. System Design for Stationary Power Generation. In: Vielstich W, Lamm A,Gasteiger H, editors. Handbook of Fuel Cell Technology—Fundamentals, Technology and Applications, 4. New York: J. Wiley; 2003. p. 683-692.

Behling, N. 2012. Current Technology Challenges and Future Research Needs. Elsevier.

Benziger Group. Gas Diffusion Layer and Flow Channel Transport. [Read: 20.3.2015] Available: http://pemfc.princeton.edu/

Björkstén, J. 2010. How to Manage a Successful Business in China. Singapore: World Scientific.

Enerdata. 2014. Coal and lignite domestic consumption. [Read: 07.02.2015]. Available: https://yearbook.enerdata.net/coal-and-lignite-world-consumption.html

EPA united states environment protection agency. 2014. Fine particle (PM2.5) designations. [Read: 3.7.2015] Available: http://www.epa.gov/pmdesignations/faq.htm#0

EPA Urban Dynamometer Driving Schedule (UDDS). [Read: 21.02.2015]. Available: www.epa.gov/otaq/emisslab/methods/uddsdds.gif

Fuel Cell Energy, 2013. Types of fuel cells. [Read: 10.3.2015]. Available: http://www.fuelcellenergy.com/why-fuelcell-energy/types-of-fuel-cells/

Fuel Cell Today, 2012. Technology. [Read: 12.2.2015]. Available: http://www.fuelcelltoday.com/technologies

Fuel Cell Today, 2012. History of Fuel Cell Development in China. [Read: 16.3.2015]. Available: http://www.fuelcelltoday.com/media/1587227/fuel_cells_and_hydrogen_in_china_2012.pdf

Fuel Cell Today, 2013. Applications. [Read: 16.2.2015]. Available: http://www.fuelcelltoday.com/applications

Fuel Cell Today. PEMFC [read: 15.3.2015] available: http://www.fuelcelltoday.com/technologies/pemfc

Fuel Cells 2000, 2015. Types of fuel cells. [Read: 10.3.2015]. Available: http://www.fuelcells.org/base.cgim?template=types_of_fuel_cells

Fuel Cell Market. Low Cost Volume Metal Fuel Cell Plate Manufacturing [Read: 20.3.2015] Available:

http://www.fuelcellmarkets.com/Borit_fuel_cell_bipolar_plate_manufacturing/forming_relationships/3,1,28733,18,29076.html

Hy Web. H2 Mobility: Hydrogen Vehicles. [Read: 07.03.2015]. Available: www.netinform.net/h2/H2Mobility/Default.aspx

James, B. & Spisak, A. 2012. Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2012 Update. Arlington: Strategic Analysis Inc. Available:
http://energy.gov/sites/prod/files/2014/03/f12/sa_fc_system_cost_analysis_2012.pdf

James, B. D. 2012. Fuel Cell Transportation Cost Analysis, Preliminary Results, Proc.

Kallio, T. 2015. Aalto University News & Events. [Read: 05.03.2015]. Available: http://www.aalto.fi/en/current/news/2015-02-18-002/

Khurmi, R., Sedha, R., 2013. Materials Science. 5th Edition. Place of publishing unknown: S. Chand & Company Ltd.

Konrad G, Sommer M, Loschko B, Schell A, Docter A. System Design for Vehicle Applications: DaimlerChrysler. In: Vielstich W, Lamm A, Gasteiger H, editors. Handbook of Fuel Cell Technology—Fundamentals, Technology and Applications, 4.New York: J. Wiley; 2003. p. 693-713.

Luo, Y. 2002. Multinational Enterprises in Emerging Markets. Copenhagen: Copenhagen Business School Press.

Maiyalagen,T.& Pasupathi, S. 2010. Components for PEM Fuel cell: An overview. South African Institute for Advanced Materials Chemistry (SAIAMC), University of the Western Cape.

Masten DA, Bosco AD. System Design for Vehicle Applications: GM/Opel. In: Vielstich W, Lamm A, Gasteiger H, editors. Handbook of Fuel Cell Technology—Fundamentals, Technology and Applications, 4. New York: J. Wiley; 2003. p. 714-724.

Oliver, N., Holweg, M & Luo, J. 2009. The past, present and future of China's automotive industry: a value chain perspective. Int. J. Technological Learning, Innovation and Development, 2. British: The University of Edinburgh; 2009. p. 76-118.

ORNL (Oak Ridge National Laboratory). Fuel Cell R&D. [Read: 20.3.2015] Available: http://web.ornl.gov/sci/eere/research_fuelcell_research.shtml

Pehnt M. Life Cycle Analysis of Fuel Cell System Components. In: Vielstich W, Lamm A, Gasteiger H, editors. Handbook of Fuel Cell Technology—Fundamentals, Technology and Applications, 4. New York: J. Wiley; 2003. p. 1293-1317.

Seifried, D., Witzel, W., 2010. Renewable Energy – The Fact. 3rd Edition. Freiburg: Energieagentur Regio Gmbh.

Solid state Ionics and electroceramics research group, 2013. Fuel Cells for Sustainable Energy --- Science meets social responsibility. [Read: 12.2.2015]. Available: http://addis.caltech.edu/research/FCs%20for%20sustain%20energy.html

Stone R. Competing Technologies for Transportation. In: Hoogers G, editor. Fuel Cell Technology Handbook. Boca Raton, FL: CRC Press; 2003.

The wall street journal, 2013. In China, Air Pollution Rules Spur Big Car Purchases. [Read:7.3.2015] Available:
http://www.wsj.com/news/articles/SB10001424127887323420604578651471077993746

Time, 2013. The sacariest environment fact in the world. [Read: 8.3.2015] Available:
http://science.time.com/2013/01/29/the-scariest-environmental-fact-in-the-world/

Watts, J, 2009. Theguardian. [Read: 15.3.2015] Available:
http://www.theguardian.com/environment/2009/apr/02/china-e6-electric-car

Wired Mag, Nov. 26, 2007. China Learns to Drive. [Read: 19.3.2015] Available:
http://www.china-mike.com/facts-about-china/facts-transportation-autos-car-culture/

Witinski, P. Catalyst Layer of a PEM Fuel Cell Membrane. School of engineering & appkied scences, University of Rochester.

APPENDICES

Appendix 1 Institutes and Research Companies

Dalian Institute of Chemical Physics (DICP)

Company	Location, Dalian; established 1949; 100 permanent fuel cell staff (plus 100 students)
Fuel Cell Interests	Researching key materials and system integration for PEMFC; DICP also has DMFC and SOFC research interests. Developed China's first AFC system for the space program
Website	http://www.english.dicp.ac.cn/

Shanghai Everpower Technologies Ltd

Company	Location, Shanghai; established June 2009; 40 employees, plans to expand in 2012
Fuel Cell Interests	Developing small PEMFC systems up to 5 kW for backup power and small vehicles. Staff have 15-20 years fuel cell experience gained at fuel cell companies such as Ballard
Website	http://en.hjpower.com/index.html

Horizon Fuel Cell Technologies

Company	Shanghai (Headquartered in Singapore); established 2003; 130 staff (~15 in Singapore)
Fuel Cell Interests	PEMFC technology for portable power and small transportation applications. Scaling up its units for telecoms backup power, consumer electronics charging and city-vehicles
Website	http://www.horizonfuelcell.com/

Hydrogen God Fuel Cell Ltd

Company	Location, Tianjin; established March 2011; 6 employees
Fuel Cell Interests	Focussing on sub-1 kW PEMFC for emergency power and small fuel cells for e-bikes. Once established intends to develop larger units for UPS and transport applications
Website	Under Development

JS Power

Company	Location, Zhenjiang; established 2010; 60 employees but plans to expand in 2012
Fuel Cell Interests	Focussing on H_2 production and storage. Has its own powdered H_2 production technology. Has a range of PEMFC products from a 4 W portable charger up to a 5 kW system
Website	http://www.jspowerinc.com

Palcan Energy Corp.

Company	Location, Suzhou, Headquartered in Canada; established 1998; 30 employees
Fuel Cell Interests	Integrates PEMFC technology for backup power, portable and e-bike applications. Developed a proprietary H_2 production system using powdered hydride and water
Website	http://www.palcan.com/

Pearl Hydrogen Technology Co. Ltd.

Company	Location, Shanghai; established January 2006; 35 staff (50% in manufacturing)
Fuel Cell Interests	Focussed on commercialisation of PEM fuel cells for telecoms backup and light vehicles targeting greater lifetime and lower cost. Manufacturing capacity: 2 MW / year
Website	http://www.pearlhydrogen.com/

SAIC Motor Corporation Ltd

Company	Location, Shanghai; domestic market share ~20%; >100,000 employees
Fuel Cell Interests	Involved in all major domestic FCEV and fuel cell bus demonstrations to date. Plans to manufacture 22 FCEV for employees by 2013 and >1,000 for commercial sale from 2015. Controls 34.5% of Dalian-based fuel cell company Sunrise Power Company Ltd.
Website	http://www.saicgroup.com/english/index.shtml

Shanghai Shen-Li High Tech Co. Ltd

Company	Location, Shanghai; established June 1998;
Fuel Cell Interests	PEMFC development and transport fuel cell demonstration are main focuses. Also has a 10 kW hydrogen fuelled stationary product and a 100-300 W portable system
Website	http://www.sl-power.com/index_en.html

Space power

Company	Location, Shanghai; part of the China Aerospace Science and Technology Corporation
Fuel Cell Interests	Has developed PEMFC for transport applications, collaborates with universities and automotive companies. Also has 1 kW DMFC system for portable power.

Shanghai Sunwise Energy Systems Company Ltd

Company	Location, Shanghai; established 2004;
Fuel Cell Interests	Develops hydrogen refuelling stations, including the permanent installation at Anting and a number of mobile units. Developing on-board storage of hydrogen for FCEV.
Website	http://www.sunwise.sh.cn/ also runs: http://www.china-hydrogen.org/

Sunrise Power Company Ltd

Company	Location, Dalian; established 2001, a spin-off from DICP; 140 staff (~50 academic)
Fuel Cell Interests	Full spectrum of research from catalysts to fuel cell systems, offers technical support and owns 200-300 fuel cell patents. Co-located with the National Engineering Research Center of Fuel Cell & Hydrogen Technology
Website	http://www.fuelcell.com.cn/english/index.html

Tsinghua University

Company	Location, Beijing; major fuel cell research centre; 10 staff plus 30 post-graduate students
Fuel Cell Interests	Focus is on PEMFC and DMFC but also researching low temperature (500 ^{o}C) SOFC
Website	http://www.tsinghua.edu.cn/publish/then/index.html

Wuhan University of Technology

Company	Location, Wuhan; established 2000 with the amalgamation three universities. Can trace its original roots back to the Ziqiang Institute in 1893
Fuel Cell Interests	PEMFC modelling and development. Researching fuel cell engines with DongFeng. Channels development work and IP through partner WUT New Energy Co. Ltd.
Website	http://w3.whu.edu.cn/en/

WUT New Energy Co Ltd

Company	Location, Wuhan; established May 2006, a spin-off from Wuhan University of Technology; 50 staff (20 academic) plus >100 students
Fuel Cell Interests	PEMFC only. Catalysts, membrane electrode assemblies, recent investment in semi-automated MEA production. MEA Capacity 5,000 m^2 /year
Website	tp://www.wutenergy.com/index.asp

FuelCellToday. 2012. Fuel Cells and Hydrogen in China 2012. Available: http://www.fuelcelltoday.com/media/1587227/fuel_cells_and_hydrogen_in_china_2012.pdf

Appendix 2

Table 1.06: Final energy consumption by fuel[1] 1970 to 2013

Return to Title page

Thousand tonnes of oil equivalent (ktoe)

	Coal	Coke and breeze[2]	Other solid fuels[3]	Coke oven gas	Town gas	Natural gas[4]	Electricity	Heat sold	Bioenergy and waste[5]	Petroleum	Total [2,3]
1970	29,822	12,950	2,184	1,164	10,746	3,662	16,542	-	-	68,511	145,977
1971	24,855	10,134	2,333	1,118	8,882	9,431	17,021	-	-	69,568	143,589
1972	20,366	9,222	2,396	1,111	8,094	15,063	17,643	-	-	72,129	146,205
1973	20,313	9,721	2,280	1,290	5,852	20,584	18,898	-	-	74,620	153,744
1974	19,003	8,555	2,156	975	3,836	25,736	18,356	-	-	68,072	146,818
1975	16,172	7,391	1,977	1,038	1,796	29,212	18,293	-	-	64,776	140,751
1976	15,162	8,016	1,771	1,091	534	33,204	18,537	-	-	65,981	144,407
1977	15,502	7,220	1,748	1,010	174	35,393	18,948	-	-	67,361	147,444
1978	14,454	6,681	1,642	899	81	37,766	19,336	-	-	68,208	149,146
1979	15,124	7,279	1,579	977	91	41,262	20,223	-	-	68,937	155,521
1980	12,854	3,975	1,504	642	76	41,647	19,252	-	-	62,408	142,394
1981	11,960	5,136	1,317	665	65	41,828	18,945	-	-	58,420	138,346
1982	12,169	4,660	1,290	605	55	41,990	18,567	-	-	57,360	136,726
1983	11,688	4,899	1,267	635	45	42,242	18,856	-	-	56,453	136,111
1984	9,673	4,995	796	537	43	43,251	19,280	-	-	57,158	135,753
1985	12,124	5,338	1,108	768	40	45,940	20,118	-	-	56,416	141,867
1986	12,348	4,869	1,063	778	28	46,622	20,763	-	-	59,245	145,719
1987 [6]	10,174	5,343	1,098	821	28	48,096	22,252	-	-	58,325	146,132
1988	9,738	5,605	962	771	8	46,277	22,811	-	443	61,952	148,569
1989	8,909	4,645	845	613	-	44,780	23,254	-	447	62,685	146,180
1990	8,122	4,333	804	602	-	46,052	23,601	-	451	63,302	147,268
1991	8,605	4,006	799	570	-	49,676	24,170	-	467	63,525	151,818
1992	8,101	3,866	723	534	-	48,357	24,206	-	672	64,632	151,091
1993	7,617	3,833	758	560	-	49,282	24,607	-	652	65,437	152,747
1994	6,855	3,919	795	590	-	49,935	24,353	-	901	65,196	152,548
1995	5,279	3,867	654	576	-	50,091	25,279	-	956	63,679	150,384
1996	4,429	984	821	439	-	56,536	26,453	-	954	66,096	157,019
1997	4,331	846	667	457	-	54,162	26,759	-	930	65,418	153,902
1998	3,716	889	682	385	-	55,856	27,143	-	865	66,107	155,921
1999	3,458	906	625	205	-	55,148	27,751	2,498	688	65,116	156,534
2000	2,733	848	590	216	-	57,077	28,325	2,515	672	66,293	159,365
2001	2,704	766	539	154	-	57,814	28,609	2,327	656	67,084	160,926
2002	2,209	737	459	78	-	55,234	28,667	2,084	682	66,099	156,476
2003	2,078	680	420	53	-	56,701	28,910	1,787	709	66,772	158,147
2004	1,988	595	411	67	-	57,080	29,144	1,258	715	68,647	159,936
2005	1,695	559	370	79	-	55,384	29,981	1,268	798	69,516	159,676
2006	1,627	504	378	106	-	52,633	29,684	1,245	952	69,836	157,042
2007	1,788	524	359	101	-	49,961	29,377	1,338	1,235	69,528	154,259
2008	1,845	452	403	92	-	51,796	29,391	1,465	1,879	66,535	153,899
2009	1,733	395	212	49	-	46,712	27,665	1,206	2,139	63,409	143,548
2010	1,912	346	238	97	-	51,972	28,274	1,266	2,569	63,223	149,985
2011	1,772	312	209	59	-	42,916	27,333	1,206	2,482	61,563	137,918
2012	1,747	347	197	43	-	47,248	27,329	1,226	2,424	60,952	141,539
2013	1,967	509	231	62	-	47,941	27,283	1,292	2,868	60,297	142,460

1. Excluding non-energy use of fuels.
2. Blast furnace gas is included in coke and breeze up to 1995 and covers electricity transformation, use by ovens and losses.
   From 1996 onwards, blast furnace gas is included in the total and covers just coke ovens and losses, which is consistent with the methodology used for compiling the energy balances. Creosote and pitch are included in the total until 1993.
3. Includes, from 1994, manufactured liquid fuels.
4. Includes colliery methane. Up to 1988 also includes non-energy use of natural gas.
5. Predominantly used for renewable heat; includes liquid biofuels from 2006. Consumption of renewable electricity is included under 'Electricity'.
6. Electricity data for all generating companies are only available from 1987 onwards.
   Before 1987 the data are for major power producers, transport undertakings and industrial hydro and nuclear stations only.

Source

Department of Energy and Climate Change - Digest of UK Energy Statistics Annex, Table 1.1.5.

Department of energy & climate change – digest of UK Energy Statistics Annex, 2014
Available: https://www.gov.uk/government/statistics/energy-consumption-in-the-uk